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A new approach for spatial optimization of crop planting structure to balance economic and environmental benefits

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ABSTRACT

With limited land resources and water scarcity, scientifically optimizing crop layouts is essential for ensuring the sustainable development of agricultural systems. This study introduces a hybrid approach to crop layout optimization in Heilongjiang Province, focusing on planting the most suitable crops in appropriate regions. The approach integrates multi-objective interval parameter programming, life cycle assessment, maximum entropy (MaxEnt), and the dynamic conversion of land use and its effects (Dyna-CLUE) model. The results indicate that slope, population density, and mean temperature of the coldest quarter are the main factors influencing the distribution of rice, maize, and soybeans, respectively. Highly suitable areas for rice cultivation account for 10.3 % of the province's land area, primarily in the Three Rivers Plain. Comparisons of the optimal planting structure from the optimized simulation to the 2021 baseline show that although economic benefits may decrease by 1.7 % to 4.2 %, the crop carbon footprint could be reduced by 9.3 % to 10.7 %. These findings highlight the importance of balancing economic and environmental benefits in optimizing crop structures. Furthermore, the proposed model shifts the focus from quantitative optimization of crop planting to spatial optimization, emphasizing the importance of determining where crops should be planted rather than solely focusing on how much to plant.

1. Introduction

Cropland resources are essential natural conditions for ensuring production and living, and they are also crucial strategic resources for agricultural production and sustainable development. With the rapid population growth, by 2050 we will need to produce 60 % more food to feed a world population of 9.7 billion (FAO, 2013). Agricultural development faces challenges such as limited development space and arable land degradation (Gomiero, 2016). Adjusting the spatial distribution of grain sowing areas and optimal crop planting structure are important strategies to increase grain production (Wu et al., 2014). On the one hand, scientific and rational planting arrangements can increase the yield of major grain crops, ensuring a stable food supply despite uncertainties such as climate change, natural disasters, or market fluctuations (Anwar et al., 2013). On the other hand, optimal crop planting structures will alter the material and energy flows in agricultural land systems, positively impacting water resource utilization, greenhouse gas emissions, and ecosystem service functions (Wang et al., 2021).

The structure of crop planting is heavily influenced by natural endowments, with geographical and environmental factors significantly affecting the planting structure and yield fluctuations of all crops. Additionally, human planting activities play a critical role in determining the crop planting patterns of a region. For instance, farmers often consider the availability of water sources and irrigation water supply when choosing to plant rice (Mariano et al., 2012; Surendran et al., 2021). Socio-economic and political changes are primary drivers of shifts in crop planting structures (Li et al., 2018). Neglecting the influence of economic factors and the interplay between economy and environment may result in an incomplete understanding of the mechanisms underlying changes in crop planting structures (Guo et al., 2024). Furthermore, the key drivers for maintaining stable and sustainable food production vary by region (Wezel et al., 2020). Balancing economic and environmental benefits and determining the optimal distribution of major food crops is a critical challenge that requires immediate

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